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Published version

ROWLEY, Lee J, CHURCHILL, Sarah M., DUNN, Marcus and WHEAT, Jonathan (2021). Effect of hurdling step strategy on the kinematics of the hurdle clearance technique. Sports Biomech.

Sports Biomechanics

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/rspb20

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SPORTS BIOMECHANICS
https://doi.org/10.1080/14763141.2021.1970214

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Effect of hurdling step strategy on the kinematics of the hurdle clearance technique

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ABSTRACT

Athletes use either an eight-step or a seven-step strategy to reach the first hurdle in the 110 m hurdles event. This study investigates the effect of step strategy on the hurdle clearance technique and spatio-temporal parameters of the four steps prior to hurdle clearance. Two-dimensional video data were collected in the sagittal plane from 12 male sprinters, grouped as seven-step (n = 6) or eight-step (n = 6) strategists. The take-off distance was 0.20 m further from the hurdle and the touchdown was 0.42 m closer to the hurdle for seven-step athletes. Additionally, seven-step athletes reduced the length of the final step before hurdle take-off by 0.14 m compared with the previous step, whereas the eight-step athletes extended their final step by 0.17 m. There was negligible difference between the mean horizontal velocities of the two groups throughout the hurdle clearance (0.02 m/s) or the approach time to the first hurdle from the block clearance (0.01 s). This presents an important first insight into the effect of the step strategy on the first hurdle kinematics. Our findings identify the take-off and touchdown distance parameters of the hurdle clearance technique, and approach step characteristics for a successful seven- or eight-step approach strategy to be employed.

ARTICLE HISTORY
Received 19 May 2021
Accepted 10 August 2021

KEYWORDS
Approach; sprint; acceleration; track and field; athletics

Introduction

The aim of the 110 m sprint hurdles event is to cover the horizontal distance, clearing each of the 10 hurdles in the fastest time. Therefore, as with flat sprinting, the ability to generate a high level of horizontal velocity is ultimately the key factor for success. The constraints on the inter-hurdle distance (9.14 m) dictate that a three-step pattern between hurdles is the most suitable for all athletes, but step strategy prior to the first hurdle differs between athletes. Some hurdlers use an eight-step approach, whereas others use a seven-step approach. An eight-step approach has previously dominated coaching practice. Every Olympic athlete prior to the 1960 Olympic Games favoured the eight-step strategy (Pinho et al., 2017). Despite historical resistance, the seven-step approach has now become commonplace among senior world-class hurdlers (Bezodis et al., 2019).

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When athletes leave the starting blocks, they accelerate via a suitable step strategy which positions them correctly for clearance at the first hurdle. Elite hurdlers take-off 2.01–2.40 m from the first hurdle (González-Frutos et al., 2020; Mann, 2011; Tidow, 1991), leaving 11.32–11.71 m from the start line to the point of take-off for the athlete to generate horizontal acceleration.

There are several parameters which have previously been used to quantify the technical success of the hurdle take-off phase (Iskra & Čoh, 2006). The most important of these measurements is to identify the position and trajectory of the whole body centre of mass (CoM). The smaller the decrease in the horizontal velocity of the CoM across the hurdle, the more technically effective the hurdle clearance.

Take-off directly affects the success of the hurdle clearance, the touchdown phase, and the inter-hurdle steps (Mann, 2011). The deviation angle is a measure of the absolute position of the CoM in relation to the metatarsal phalangeal (MTP) joint of the take-off foot and a line horizontal with the ground from the MTP towards the hurdle. Previous research suggests that this angle is a key parameter which defines the success of the take-off phase, defining the trajectory of the CoM and the hurdle flight time (Čoh et al., 2000). Better hurdlers have a deviation angle which is less than 70° (Li et al., 2011; Wen, 2003). There has been no documented research into the first hurdle clearance where athletes have been grouped according to step strategy. Therefore, whether both seven- and eight-step athletes take-off with an angle of less than 70° is currently unknown.

Effective clearance of the first hurdle is critical and if the athlete takes off too far from the hurdle, the path of the CoM is lengthened via both increases in the horizontal and vertical distances over which it must travel. Upon crossing the hurdle, the athlete must actively extend the lead leg hip joint and re-establish ground contact as opposed to passively waiting for the ground contact to occur.

The optimal ratio of take-off to touchdown distance is a key element which defines the success of the hurdle clearance (Amara et al., 2019; Mann, 2011). Sidhu and Singh (2015) proposed a ratio of 65:35 for take-off and touchdown distance step lengths. This ratio allows enough space to rapidly extend the lead leg anteriorly prior to crossing the hurdle and considering the need to re-establish ground contact as immediately practical. When considering the biomechanical implications of the seven- and eight-step approach strategies, it is likely that the take-off ratio will be increased for the seven-step athletes because they have one step fewer to position the foot for take-off. It is particularly important to consider the kinematics of the touchdown phase and the ground contact time. This phase is crucial for successful execution of the inter-hurdle steps and is directly affected by the success of the take-off position (Čoh & Iskra, 2012).

Unnecessary increases in ground contact time of the touchdown foot indicate a ground contact ahead of the CoM position, leading to negative horizontal braking forces and limiting the velocity which can be maintained between the hurdles. The cumulative result of which is a detrimental effect upon overall race performance. Elite athletes have been found to complete both shorter ground contact and flight times throughout the hurdle clearance phase than high-level athletes (González-Frutos et al., 2019). Should seven-step athletes compensate for having one fewer step by taking off further from the first hurdle, the position of the touchdown may as a consequence, be closer to the hurdle, making it difficult for the seven-step athletes to position the CoM correctly.

A fast hurdle clearance is made possible by rapid flexion and extension phases of the lead leg hip (Arnold, 1992). Despite this understanding, there is only one study where the velocity of the lead leg hip action has been recorded (Salo, 2002). However, in the flat sprint literature, the hip action was found to be extremely important throughout both acceleration (Charalambous et al., 2012) and maximal velocity phases (Mann & Sprague, 1980). In hurdling, as athletes increase their horizontal velocity, the necessity to rapidly flex and extend the lead leg hip becomes more important to avoid hitting the hurdle with the leading foot, and to re-establish ground contact in the correct position. Failure to rapidly extend the lead leg hip upon crossing the hurdle will cause the athlete to apply unwanted horizontal braking forces upon ground contact, as ground contact will be established ahead of the whole body CoM. If seven-step athletes are taking off further from the hurdle, with more available space to raise the lead leg, a slower lead leg hip flexion will lead to a technically poorer hurdle clearance as the hurdle flight time increases.

A three-step pattern between hurdles is accepted as the most effective method for negotiating the constraints of the inter-hurdle distance (9.14 m). Athletes make alterations to normal sprint step characteristics (ground contact time, flight time and step length) to successfully position themselves for clearance of the next hurdle, and to satisfy the four ground contacts required of a three-step pattern. These alterations must allow for the generation of further acceleration throughout the first phase of the event (positive acceleration; 0–30 m), and maintenance of optimum horizontal velocity throughout the middle (maintenance; 30–70 m) and final phases (negative acceleration; 70–110 m). To effectively satisfy each phase, athletes reduce step lengths between the hurdles, with only the second comparable in step length to a normal sprint step length (McDonald & Dapena, 1991). Irrespective of the approach step strategy, there should be no detrimental effect to the intra-hurdle step kinematics. Although it is not known how the approach strategy affects the inter-hurdle steps, any differences in the dynamics of the touchdown (both in absolute position and in relation to the CoM) are likely to affect primarily the first inter-hurdle step, and the ability of the athlete to maintain horizontal velocity into the following hurdle.

As the athletes approach the first hurdle, the dynamics of each step change in preparation for hurdle clearance. This is particularly evident when comparing seven- and eight-step strategists, whereby there is a need to balance the development of horizontal velocity with suitable step lengths to position for optimum hurdle clearance. Essentially, there is a functional difference between the strategy used for acceleration and the preparation for the hurdle clearance.

To date, only one study has differentiated participant groups by the first hurdle step strategy (Rowley et al., 2021). This omission from the methods, may affect the findings among other comparative studies of the first hurdle clearance technique. Sprint hurdlers reduce both step length and flight time prior to take-off (Mann, 2011). It is therefore not possible to compare like-for-like steps from the block clearance as the seventh step serves a different purpose for the different strategies. A more suitable method is to contextualise steps with reference to the hurdle, comparing the 'take-off step', the 'take-off step minus one', the 'take-off step minus two' and the 'take-off step minus three'.

The aim of this study was to investigate the effect of the first hurdle step strategy on the kinematics of the hurdle technique, and the spatio-temporal characteristics of the seven- and eight-step approaches throughout the final four approach steps. It was hypothesised that seven-step athletes would clear the first hurdle differently to eight-step athletes to accommodate having one fewer approach step. The take-off distance from the first hurdle, hurdle step length and oscillations pertaining to the centre of mass are parameters which are likely to differ; however, this is not yet known.

Methods

Participants

Twelve male sprint hurdlers (mean age: 22 ± 2.11 years; body mass: 79.4 ± 11.8 kg; stature: 1.83 ± 0.07 m) volunteered to take part in the study. All were experienced athletes, had a personal best performance time of under 15.00 s in the senior men's 110 m hurdles event (mean: 14.13 ± 0.39 s; range from 13.48 to 14.68 s) and were ranked in the top 35 in Great Britain at the time of data collection. Participants comprised two groups of six, based on the number of steps taken to the first hurdle during a competitive performance (mean personal best: seven-step athletes: 14.04 ± 0.42 s; eight-step athletes: 14.21 ± 0.42 s). Research study procedures were approved by Sheffield Hallam University's Research Ethics Committee. Participants were provided with an information sheet and gave written informed consent before taking part.

Data collection

Data were collected at seven locations in order to minimise disruption to the athletes' normal training. Standard outdoor athletics tracks were used at the Loughborough University Athletics Centre, Leeds Beckett University Athletics Centre and Brunel University Sports Park. Standard indoor athletics facilities were used at Birmingham Alexander Stadium, University of Bath Sports Training Village, Gateshead International Stadium and Lea Valley Athletics Centre. Each individual athlete's data were collected during a single session. All participants wore their usual running spikes and skin-tight clothing.

Anthropometric data were collected of the participant's mass (BC543, Tanita, Amsterdam, The Netherlands), stature (Marsden Leicester height measure, Rotherham, UK) and leg length (measured in the anatomical standing position using a tape measure from location of surface markers at ankle joint centre to hip joint centre).

Each participant completed a self-managed warm-up before carrying out three starts from blocks in response to an audible stimulus. Once leaving the blocks participants were required to clear the first two hurdles at their normal race intensity. Hurdle spacings and specifications were in-line with 2017–2018 International Association of Athletics Federations (International Association of Athletics Federations [IAAF], 2016) competition rule 168 (hurdle height, 1.067 m; start line to first hurdle distance, 13.72 m; first hurdle to second hurdle distance: 9.14 m). A full recovery was permitted between trials (at least 5 minutes). If participants knocked down the first hurdle, the trial was not included. Consequently, not all participants were able to complete three successful trials. In total, 16 trials were captured for the seven-step group and 16 trials for eight-step group. The successful trial was selected for those who completed only one trial and the second successful trial was selected from those who completed either two or three successful trials.

High-speed video footage (200 Hz) of the hurdle clearance was collected using a single camera aligned with the first hurdle. A second high-speed camera was aligned mid-way between the start line and the first hurdle is to capture the spatio-temporal parameters of the approach steps. All footage was collected with Phantom Miro M110 high-speed cameras (Vision Research, Wayne, New Jersey, USA) which were positioned 20 m perpendicular to the centre of the running lane and provided images of the sagittal plane. Cameras were set up in accordance with Figure 1 and identified as either the 'hurdle' or 'overview' camera. Cameras were manually focused, and the field of view was set to 6.00 m wide for the hurdle camera and 19.72 m wide for the overview camera. Shutter-speed was $^{1}/_{500}$ s (exposure of 2000 μs) and aperture was fully open for each camera (Figure 1).

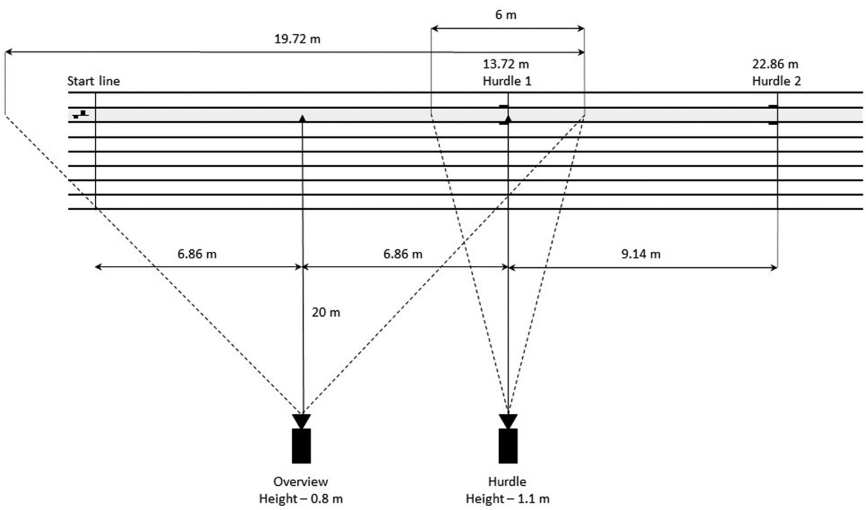

Figure 1. Plan view of camera set-up for hurdle trials (not to scale).

Data processing

Calibration data were collected using a chequerboard method for the start camera and using track markings and hurdle height for linear scaling of the overview camera. To calibrate the hurdle camera, a chequerboard (7 × 7 squares each measuring 0.08 m) was manually held in different positions and orientations across the camera image and a series of frames captured. These were used to calibrate the intrinsic and extrinsic camera parameters using Check2D software (V1.5; Centre for Sports Engineering Research, Sheffield Hallam University, UK). Track markings were used to determine the parameters of the overview camera, completed using SimiMotion 9.2.1. (Simi Reality Motion Systems GmbH, Max-Planck-Strasse 11, 85716 Unterschleissheim, Germany). Footage was manually digitised using SimiMotion 9.2.1 software with an additional 10 frames at the start and end of the required hurdle camera footage to allow for endpoint errors due to filtering (Smith, 1989).

Eighteen anatomical landmarks were identified and digitised to create a 16-segment kinematic model based upon DeLeva (1996). Segments were: head, trunk, left and right upper arms, forearms, hands, thighs, shanks, and feet. Trunk data were created from virtual coordinates of mid-hip (mid-point between left and right hip joint centres) and mid-shoulder (mid-point between left and right shoulder joint centres). Gait events were determined by visual inspection of the footage.

Raw image coordinate data were filtered using a second-order low-pass Butterworth filter with a cut-off frequency of 8 Hz. The cut-off frequency was identified via residual analysis (Winter, 1999). For the hurdle camera, raw image coordinate data and camera calibration data were subsequently exported, and planar position data reconstructed (Dunn et al., 2012) using Matlab R2017a (The MathWorks, Natick, MA, USA). A comprehensive review of the available literature yielded a total of 34 parameters which were investigated, 25 from the hurdle camera (Table 1), five from the overview camera (Table 2) and four from the anthropometric data (Table 3).

Table 1. Description of technical variables calculated from the hurdle camera view.

Parameter	Description
Hurdle step length (m)	Horizontal distance from the metatarsophalangeal joint (MTP) of the take-off foot to the MTP of the touchdown foot.
Take-off distance (m)	Horizontal distance from the MTP of the take-off foot to the base of the hurdle.
Normalised take-off distance	Non-dimensional normalisation. Take-off distance divided by leg-length.
Touchdown distance (m)	Horizontal distance from the MTP of the touchdown foot to the base of the hurdle.
Take-off distance (%)	Percentage of the hurdle step length occurring prior to the hurdle from the MTP of the take-off foot to the base of the hurdle.
Take-off step ground contact time (s)	Time that the take-off foot can positively be identified as in contact with the ground to the first frame of loss of ground contact.
Touchdown step ground contact time (s)	Time that the touchdown foot can positively be identified as in contact with the ground to the first frame of loss of ground contact.
Hurdle flight time (s)	Time that the take-off foot loses ground contact to the first frame of ground contact of the touchdown foot.
CoM mean horizontal velocity (m/s)	Mean horizontal velocity of the CoM throughout the hurdle clearance phase.
CoM take-off vertical velocity (m/s)	Vertical velocity of the CoM at hurdle take-off
CoM touchdown vertical velocity (m/s)	Vertical velocity of the CoM at hurdle touchdown
CoM height at take-off (m)	Height of the CoM from the ground at the point of take-off.
CoM height at touchdown (m)	Height of the CoM from the ground at the point of touchdown.
CoM change (m)	Change in the vertical position of the CoM from take-off to touchdown.
CoM maximum height (m)	Maximum relative height of the CoM above the height of the hurdle throughout the hurdle clearance phase.
CoM height above hurdle (m)	Height of the CoM as it crosses the hurdle plane.
CoM difference at take-off to above hurdle (m)	Change in the height of the CoM from take-off to height above hurdle.
CoM difference above hurdle to touchdown (m)	Change in the height of the CoM from height above hurdle to touchdown.
CoM take-off angle (°)	Absolute angle of the CoM from the first frame of loss of ground contact of the take-off foot and the following frame.
MTP to CoM take-off angle (°)	Absolute angle between the CoM and the MTP of the take-off foot at take-off.
MTP to CoM touchdown angle (°)	Absolute angle between the CoM and the MTP of the touchdown foot at touchdown.
Lead hip mean angular velocity throughout take-off (°/s)	Mean angular velocity of the lead leg hip throughout the ground contact phase of the take-off foot.
Lead hip mean angular acceleration throughout take-off (°/s^2)	Mean angular acceleration of the lead leg hip throughout the ground contact phase of the take-off foot.
Lead hip mean angular velocity throughout touchdown (°/s)	Mean angular velocity of the lead leg hip from the first frame of lead leg hip extension throughout the hurdle clearance phase, to the point of ground contact of the lead leg foot.
Lead hip mean angular acceleration throughout touchdown (°/s^2)	Mean angular acceleration of the lead leg hip from the first frame of lead leg hip extension throughout the hurdle clearance phase, to the point of ground contact of the lead leg foot.

Table 2. Description of the technique variables is calculated from the overview camera view.

Parameter	Description
Step length (m)	Horizontal distance between the MTP of the touchdown step and the MTP of the following contralateral touchdown step.
Step frequency TO-3 to take-off (Hz)	Mean number of steps taken per second from the TO-4 step loss of ground contact to the loss of ground contact of the hurdle take-off step. Calculated by dividing the time to end of fourth ground contact by the number of approach steps.
Ground contact time (s)	Time that each step foot can positively be identified as in contact with the ground to the first frame of loss of ground contact.
Flight time (s)	Time between steps that neither foot is in contact with the ground.
Approach TO-3 to take-off (s)	Time from TO-4 step loss of ground contact to the loss of ground contact of the hurdle take-off step.

Table 3. Description of anthropometric variables.

Parameter	Description
Stature (m)	Stature of seven and eight-step athlete groups.
Mass (kg)	Mass of seven and eight-step athlete groups.
Leg-length (m)	Leg-length of seven and eight-step athlete groups measured from the ankle-joint centre to the hip-joint centre.
Leg-length % of stature	Leg-length as a percentage of stature.

Statistical analysis

Independent-sample *t*-tests (SPSS for Windows, version 24.0; SPSS, Inc., Chicago, IL, USA) were performed to determine differences between the groups for all variables (Table 1, Table 2). Athlete stature, mass, leg-length, and leg-length as a percentage of stature were also compared to assess whether there was a difference between groups in anthropometric variables (Table 3). The study included the final four ground contacts prior to the hurdle clearance. The hurdle take-off step was defined as the TO step. Therefore, steps back from the hurdle take-off were defined as TO-1 (take-off step minus one) to TO-3.

To reduce the possibility of type II errors occurring from low participant numbers, the criterion alpha level was set at $p < 0.05$ for statistical significance with $p < 0.1$ accepted as a tendency. This approach has been taken by Alt et al. (2015) when investigating the lower extremity kinematics of athlete curve sprinting with low participant numbers (n = 6). Effect size was calculated for each variable using Cohen's d (Coe, 2002; Cohen, 1988). Only large effect size differences ($d \geq 0.80$) were deemed relevant and examined, in-line with Cohen's effect size suggestions, although a contextual approach was taken when considering moderate effect sizes ($d \geq 0.50$ and $d < 0.80$).

Results

Seven-step athletes were 0.08 m taller ($p = 0.047$, $d = 1.31$) than eight-step athletes and had a tendency to be heavier (11.7 kg, $p = 0.100$, $d = 1.05$). There was no difference in leg-length between the seven and eight-step athletes (seven-step; 0.91 ± 0.02 m, eight-step; 0.88 ± 0.04 m; $p = 0.290$, $d = 0.65$). There was also no difference between the groups when considering leg-length as a percentage of stature ($p = 0.360$, $d = 0.61$) (Table 4).

Table 4. Seven and eight-step group mean values (±*SD*), effect size and significant differences for technique variables.

	Seven-Step	Eight-Step	Cohen's *d*	*p*
Hurdle step length (m)	3.36 ± 0.13	3.58 ± 0.37	0.78	0.206
Take-off distance (m)	2.12 ± 0.15	1.92 ± 0.09	1.62§	0.019*
Normalised take-off distance	2.35 ± 0.19	2.18 ± 0.14	1.02§	0.110
Touchdown distance (m)	1.24 ± 0.16	1.66 ± 0.39	1.40§	0.036*
Take-off distance (%)	63.3 ± 4.46	54.2 ± 5.85	1.75§	0.120
Take-off ground contact time (s)	0.14 ± 0.02	0.13 ± 0.01	0.47	0.437
Touchdown ground contact time (s)	0.10 ± 0.01	0.10 ± 0.01	0.07	0.900
Hurdle flight time (s)	0.36 ± 0.02	0.38 ± 0.05	0.32	0.589
CoM mean horizontal velocity (m/s)	7.45 ± 0.29	7.47 ± 0.37	0.05	0.932
CoM take-off vertical velocity (m/s)	1.72 ± 0.30	1.86 ± 0.24	0.53	0.379
CoM touchdown vertical velocity (m/s)	−1.10 ± 0.30	−1.21 ± 0.32	0.37	0.537
CoM height at take-off (m)	1.15 ± 0.04	1.13 ± 0.01	0.54	0.369
CoM height at touchdown (m)	1.21 ± 0.05	1.16 ± 0.07	0.85	0.171
CoM change (m)	0.06 ± 0.07	0.03 ± 0.07	0.47	0.437
CoM maximum height (m)	1.33 ± 0.02	1.31 ± 0.03	0.62	0.305
CoM height above hurdle (m)	1.32 ± 0.02	1.31 ± 0.03	0.52	0.389
CoM difference at take-off to above hurdle (m)	0.17 ± 0.04	0.18 ± 0.02	0.10	0.872
CoM difference above hurdle to touchdown (m)	0.11 ± 0.05	0.15 ± 0.07	0.63	0.303
CoM take-off angle (°)	14 ± 2	15 ± 2	0.31	0.607
MTP to CoM take-off angle (°)	65 ± 4	65 ± 2	0.00	1.000
MTP to CoM touchdown angle (°)	82 ± 4	81 ± 7	0.20	0.671
Lead hip mean angular velocity throughout take-off (°/s)	780 ± 138	813 ± 71	0.31	0.606
Lead hip mean angular acceleration throughout take-off (°/s)	5876 ± 1830	6245 ± 820	0.26	0.662
Lead hip mean angular velocity throughout touchdown (°/s)	547 ± 81	514 ± 79	0.41	0.489
Lead hip mean angular acceleration throughout touchdown (°/s)	3099 ± 674	2724 ± 866	0.48	0.422

*Significant at $p < 0.05$; §Effect size >±0.8.

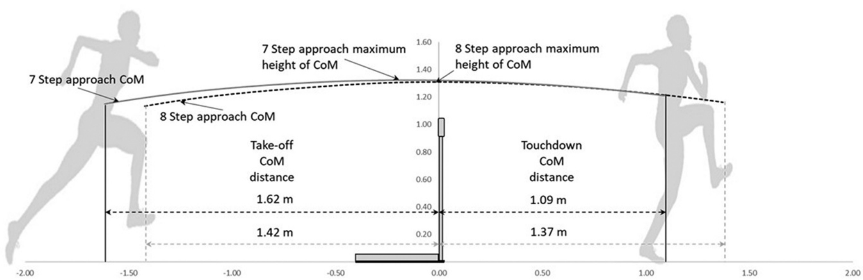

Figure 2. Trajectory of CoM over the hurdle for seven and eight-step strategies.

Seven-step athletes took off 0.20 m further from the hurdle (p = 0.019, d = 1.62) and touched down 0.42 m closer to the hurdle (p = 0.036, d = 1.40) (Figure 2; Figure 3). TO-1 was 0.33 m longer for the seven-step athletes (p = 0.048, d = 2.65) and TO-2 was 0.24 m longer (p = 0.003, d = 3.96) compared to the eight-step athletes. Ground contact times of steps TO-3, TO-2 and TO-1 were longer for seven-step athletes and yielded a large effect size (d = 1.74, 1.35 and 0.91 respectively), but did not meet the criteria to be expressed as a tendency for a difference between groups. The flight time of the TO step yielded a large effect size (d = 1.16), and the flight times of TO-2 and TO-3 were different between the two groups (p = 0.041 and 0.013 respectively). Additionally, the seven-step athletes had a 0.40 Hz lower step frequency than the eight-step athletes (p = 0.003, d = 2.26) (Table 5).

Table 5. Seven and eight-step group mean values (±*SD*), effect size and significant differences for the approach step variables.

	Seven-Step	Eight-Step	Cohen's *d*	*p*
Step length (m)				
TO-3	1.75 ± 0.07	1.45 ± 0.07	4.20[§]	0.340
TO-2	1.95 ± 0.05	1.71 ± 0.07	3.96[§]	0.003*
TO-1	2.11 ± 0.15	1.78 ± 0.10	2.65[§]	0.048*
TO	1.97 ± 0.17	1.95 ± 0.08	0.16	0.054[#]
Step GCT (s)				
TO-3	0.16 ± 0.02	0.13 ± 0.01	1.74[§]	0.797
TO-2	0.15 ± 0.01	0.13 ± 0.01	1.35[§]	0.712
TO-1	0.14 ± 0.02	0.13 ± 0.01	0.91[§]	0.234
TO	0.14 ± 0.01	0.13 ± 0.01	0.54	0.073[#]
Step flight time (s)				
TO-3	0.105 ± 0.016	0.108 ± 0.016	0.15	0.013*
TO-2	0.114 ± 0.012	0.118 ± 0.024	0.22	0.041*
TO-1	0.130 ± 0.013	0.115 ± 0.026	0.73	0.148
TO	0.113 ± 0.028	0.086 ± 0.019	1.16[§]	0.369
Approach to TO (s)	2.29 ± 0.09	2.28 ± 0.10	0.09	0.791
Step Freq (Hz)	3.06 ± 0.12	3.52 ± 0.15	3.37[§]	0.000*
Approach TO-3 to TO (s)	0.26 ± 0.03	0.24 ± 0.03	0.67	0.003*
TO-3 to TO Step Freq (Hz)	3.84 ± 0.12	4.24 ± 0.22	2.26[§]	0.003*

*Significant at $p < 0.05$; [#]Tendency at $p < 0.10$; [§]Effect size >±0.8.

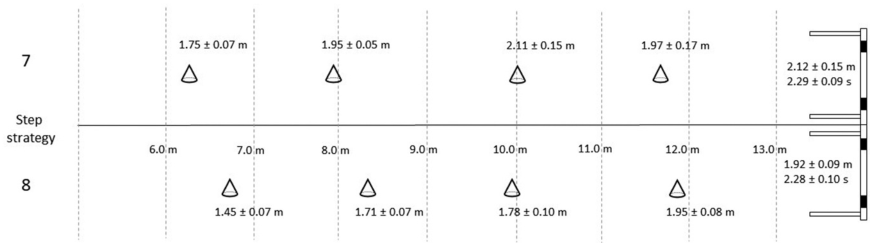

Figure 3. Seven and eight-step strategy mean (SD±) step lengths (to touchdown step cone), take-off distances and approach times to hurdle take-off (shown adjacent to hurdle) (not to scale).

Figure 3). TO-1 was 0.33 m longer for the seven-step athletes ($p = 0.048$, $d = 2.65$) and TO-2 was 0.24 m longer ($p = 0.003$, $d = 3.96$) compared to the eight-step athletes. Ground contact times of steps TO-3, TO-2 and TO-1 were longer for seven-step athletes and yielded a large effect size (d = 1.74, 1.35 and 0.91 respectively), but did not meet the criteria to be expressed as a tendency for a difference between groups. The flight time of the TO step yielded a large effect size ($d = 1.16$), and the flight times of TO-2 and TO-3 were different between the two groups (p = 0.041 and 0.013 respectively). Additionally, the seven-step athletes had a 0.40 Hz lower step frequency than the eight-step athletes ($p = 0.003$, $d = 2.26$) (Table 5).

There was no difference between the seven- and eight-step performance times from the blocks to the take-off for the first hurdle (0.01 s; $p = 0.791$, $d = 0.09$) (Table 5).

Discussion and implications

The aim of this study was to investigate the effect of the first hurdle step strategy on the kinematics of the hurdle technique and the spatio-temporal characteristics of the seven- and eight-step approaches throughout the final four approach steps. The results are in agreement with the hypothesis that seven-step athletes cleared the first hurdle differently to eight-step athletes. Seven-step athletes had a longer take-off distance. However, a longer hurdle step length and a flatter trajectory of the centre of mass did not meet the statistical criteria, although respectively, both large and moderate effect sizes were identified.

Seven-step athletes took off further away from the hurdle and touched down closer to the hurdle (Table 6). Despite differences in these parameters, there was only a moderate effect size difference in hurdle step lengths and a trivial difference in the mean horizontal velocities of the CoM throughout the hurdle step between groups. This suggests that both step strategists completed a hurdle step of similar length and horizontal velocity, but that the seven-step strategists completed a greater percentage of the hurdle step phase prior to the CoM crossing the hurdle plane. A large effect size was identified but not a significant difference when normalising the take-off distance for leg length, indicating that a difference might exist. The take-off distance, normalised to leg length, should be considered as a possible technical difference between the step strategies, and warrants future investigation. The hurdle step length should also be considered in future research and studies with larger numbers of participants may well find that the suggested differences indicated in this study become statistically evident.

Table 6. Seven and eight-step group mean anthropometric measurements (±SD), effect size and p values.

	Seven-step	Eight-step	Cohen's d	p
Stature (m)	1.87 ± 0.05	1.79 ± 0.07	1.31[§]	0.047*
Mass (kg)	85.3 ± 8.6	73.6 ± 13.3	1.05[§]	0.100
Leg-length (m)	0.91 ± 0.02	0.88 ± 0.04	0.65	0.290
Leg-length % of stature	48.3 ± 0.94	49.3 ± 2.13	0.61	0.366

*Significant at $p < 0.05$; [§]Effect size > ± 0.8.

Seven-step hurdlers in this study had a take-off-to-touchdown ratio more closely aligned to the recommendations of Sidhu and Singh (2015) with 63% of their hurdle clearance phase taking place prior to the hurdle and 37% after the hurdle. Sidhu and Singh (2015) suggested a take-off distance of 65% to allow for the kinematic requirements of a successful hurdle clearance technique, limiting unnecessary motion of the CoM and optimum take-off and touchdown positions.

Both seven- and eight-step athletes showed only minor differences between the CoM height at take-off and the CoM maximum height. However, the CoM height at touchdown was 0.05 m higher for the seven-step athletes and yielded a large effect size. Amara et al. (2019) identified the limiting vertical displacement of the CoM as a key parameter defining the success of the hurdle clearance. The results of the present study suggest that the seven-step athletes, in touching down closer to the hurdle, were able to limit undesirable negative vertical motion of the CoM to a greater extent than the eight-step athletes (Salo et al., 1997). In support of this finding, the seven-step athletes also accelerated the extension of the lead hip 375°/s^2 more throughout the touchdown phase, suggesting a more active driving of the lead leg foot towards the ground. This prevents 'floating' (a performance term whereby the body segments are not involved in independent motion and simply track the motion of the whole body CoM), and allows for an effective touchdown ground contact, and continued race acceleration (Arnold, 1992). These parameters must be interpreted with caution though as they do not satisfy either of the criteria for significance or tendency but did show moderate or large effect sizes.

Seven-step athletes completed a similar hurdle clearance trajectory to the eight-step athletes, but the clearance phase was moved closer to the start line, with the CoM passing the hurdle plane later in the hurdle clearance. Previous research has identified the CoM to cross the hurdle plane close to its maximum height although there was no consideration of the step strategy used (McDonald & Dapena, 1991). Further findings from the same study found female hurdlers CoM was at its maximum height of 0.30 m prior to crossing the hurdle plane, a similar location to the seven-step athletes in this study. As with much of the previous research, had McDonald and Dapena (1992) differentiated by step strategy the findings may well have been different, therefore step strategy should be a key consideration for inclusion in the future research, especially where first hurdle clearance is investigated.

Steps TO-1 and TO-2 were significantly longer for the seven-step athletes than the eight-step athletes, but the step prior to the take-off step (TO) had only a minor difference (0.02 m). The seven-step athletes appeared to reduce the length of the final step (TO) compared with their previous step (TO-1). However, this did not occur for the eight-step athletes who extended their final step by 0.17 m compared with the previous step. Reduction in the final step prior to take-off is a technique used by long jumpers (Hay & Nohara, 1990) to position the CoM over the take-off foot, thereby reducing horizontal braking force and accelerating the CoM into the jump phase. It is possible that the seven-step athletes were utilising a similar technique to accelerate the CoM into the hurdle clearance, allowing them to take-off from further away and consequently, complete more of the hurdle motion prior to the CoM crossing the hurdle. This may mean they are better positioned to re-establish ground contact in the lead leg closer to the hurdle, allowing an increased distance between the first and second hurdles for seven-step athletes to continue race acceleration. In-turn, this limits the degree to which seven-step athletes need to shorten their normal sprint strides to accommodate the constraints of the inter-hurdle distance. Although logical, this theory is inconclusive and further investigations should focus upon the spatio-temporal parameters of the intra-hurdle steps between the first and second hurdle, along with the intra-hurdle time differentiation between seven and eight-step strategists. It is possible that a performance difference due to the alternative touchdown position may become evident.

There was no difference in the approach times to the first hurdle between the two groups. Consequently, the step frequency over the entire approach phase was significantly lower for the seven-step athletes compared to the eight-step athletes. Whilst repositioning of the limbs is not a factor determining sprint speed (Weyand et al., 2000), the eight-step athletes must have repositioned their limbs faster than the seven-step athletes. Therefore, it is logical to conclude that the seven-step athletes generated a total horizontal ground reaction impulse of at least equivalent quantity to the eight-step athletes throughout the acceleration phase to the first hurdle. Further investigation into the kinetic parameters may prove insightful in identifying the characteristics of individual approach steps.

The effect of the first hurdle step strategy on the kinematics of the hurdle technique, and the spatio-temporal characteristics of the seven- and eight-step approaches throughout the final four approach steps was investigated in this study. Seven-step athletes took off further from the hurdle and touched down closer to the hurdle but completed a hurdle step of similar distance. This means that the position of the maximum height of the CoM occurred further from the hurdle and the trajectory of the CoM drops as it crossed the hurdle plane. The position of the touchdown being closer to the hurdle permitted a greater distance between the first hurdle touchdown and the second hurdle take-off. Subsequently, a greater distance to continue race acceleration may have been available, limiting the need to shorten step lengths between the hurdles.

There were limitations associated with this study. The use of two-dimensional analysis of footage with manual digitisation as a research method has accuracy limitations when compared with more favourable methods such as three-dimensional analysis or motion capture. However, two-dimensional analysis was deemed suitable for the design of this study due to the predominantly planar motion of the selected parameters, the field-based capability, and the non-intrusive nature of the data collection. The scope of the study was also limited to the first hurdle, and consideration of the later stages of the race may provide a more detailed insight into step strategy performance. Additionally, the relatively low number of participants and the training-based nature of the footage collection may have limitations when applied to competitive performances.

Future research should consider both the kinematic and kinetic characteristics of the inter-hurdle steps as well as the first hurdle clearance. Additionally, future studies should consider the kinetics of each of the approach steps to achieve a more comprehensive understanding of the seven-step strategy. There is an absence of research into the influence of anthropometric characteristics on the step strategy. Seven-step athletes were significantly taller, and there was indication from a large effect size that the seven-step athletes had a greater mass. If the greater mass was the result of increased muscle mass, there is the potential for the seven-step athletes to possess higher strength dynamics. Therefore, research is needed into the effect of physical characteristics on the hurdle clearance and initial acceleration, as well as investigation into the efficacy of isolated strength tests as predictors of step strategy affinity. A longitudinal study would provide useful insight into athletes transitioning from one-step strategy to the other.

Conclusion

The effect of the first hurdle step strategy on the kinematics of the hurdle technique, and the spatio-temporal characteristics of the seven- and eight-step approaches throughout the final four approach steps were investigated in this study. Seven-step athletes took off further from the hurdle and touched down closer to the hurdle but completed a hurdle step of like distance. This meant the position of the maximum height of the CoM occurred further from the hurdle and the trajectory of the CoM drops as it crossed the hurdle plane. The position of the touchdown being closer to the hurdle permitted a greater distance between the first hurdle touchdown and the second hurdle take-off. Subsequently, a greater distance to continuous race acceleration may be available, limiting the need to shorten step lengths between the hurdles.

Coaches and athletes should be aware of the further take-off distance required to complete a hurdle clearance of comparable length when performing a seven-step approach strategy, as well as the fact that their CoM will be dropping as it crosses the hurdle plane. The potential increase in available space between the first and second hurdles must also be accounted for. Performance timings between the first and second hurdles may indeed be a better measure for coaches and athletes when comparing seven and eight-step approach strategies, especially as athletes' transition from one strategy to the other. Additionally, the findings from this research may be useful to athletes competing in sports such as the long and triple jump, where foot targeting and the positioning of the CoM are essential elements for success.

To gain a clearer understanding, further studies should investigate the dynamics of the steps following the first hurdle clearance and the kinematics of the second hurdle clearance, particularly the second hurdle take-off positions of seven and eight-step athletes, along with the characteristics of the inter-hurdle steps. Future research into first hurdle clearance techniques should consider the impact of step strategy upon the research design, and the validity of the findings.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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